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ABSTRACT

This paper reports the results of student use of a TI-92 graphing calculator to solve algebra and analytic geometry problems in 9th grade Austrian classes. Students who had been trained in using the TI-92 were asked to compute x , given that a right-angled triangle had sides x , $x+3$, and $x+6$ in at least three ways, and to document their solution methods. An analysis of the frequency of a variety of methods including solving, graphing, using a table, and solving by hand is included. A similar analysis is carried out for a problem in analytic geometry. (MM)

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Using TI-92 in the 9th-Grade of Austrian Grammar Schools - Hypotheses, Experiences, Results, Problems.

In 1997/98 thirty classes of the 9th-Grade in grammar schools participated in the Austrian TI-92 project. (WURNIG, 1998). After a first phase of learning how to use the TI-92 in a successful way, the teachers of the project had to carry out a sequence of lessons in the same way in every semester. Both sequences began with a test to control the knowledge of the use of the TI-92. The goal was to find out with which exercises it would be possible to get comparable conditions in all classes.

Test I

Compute the following examples on your TI-92 and enter your minutes on the lines indicated.
(IL is the TI-92 input line, OL the TI-92 output line):

(1) Substitute the number 7 for x in the term $12x-20$:

IL: $12x-20 \mid x=7$ OL: 64

(2) Multiply the following terms: $(3x^2+7)(2x-3)$

IL: EXPAND(($3x^2+7$),($2x-3$)) OL: $6x^3-9x^2+14x-21$

(3) Convert the result of (2) into the input of (2):

IL: FACTOR($6x^3-9x^2+14x-21$) OL: $(3x^2+7)(2x-3)$

(4) Solve the equation $3x-7=4(4x+2)$ using the TI-command SOLVE:

IL: SOLVE($3x-7=4(x+2),x$) OL: $x=-15/13$

(5) Tabulate the linear function $y = 2.43 \cdot x - 5.36$ in the interval $[3,5]$ with the stepsize 1:

IL: $2.43x - 5.36 \rightarrow y1(x)$ Table:

x	y1(x)
3	<u>1.93</u>
4	<u>4.36</u>
5	<u>6.79</u>

Calculate the longest side in the rectangular triangle ($a=12.3$ and $b=16.7$):

IL: $c^2=12.3^2+16.7^2$ OL: $c^2=430.18$
 IL: $\sqrt{c^2=430.189}$ OL: $|c|=20.7408$

(7) Solve the following system of linear equations in the window GRAPH using the TI-command INTERSECTION.

1. equation: $3x + 5y = -5$ 2. equation: $2x - 3y = 22$

IL: $y1(x) = \frac{-(3x+5)}{5}$ window GRAPH:
 $y2(x) = \frac{2(x-11)}{3}$ xc: 5 yc: -4

(8) Solve the linear equation $8x - 1 - 2(5x - 4) = 0$ in the window GRAPH using the TI-command INTERSECTION (Intersect the graph of the linear function $f(x)$ with the x-axis):

IL: $y1(x) = -2x+7$ window GRAPH:
 $y2(x) = 0$ xc: 3.5 yc: 0

Statistics of the student achievements

19 classes	right $\geq 80\%$	right $> 50\%$	right $\leq 50\%$	sum
Pretest I	61%	27%	12%	100%

In the following lessons the teachers had to observe, which ways of solving a new problem students were taking when using a computer algebra system. The sequence ended with a final test.

In the **first lesson of the sequence** the thirty teachers of the 9th form had to find out the various methods the students were taking with the TI-92, when they had to **solve a quadratic equation for the first time**. As the co-ordinator I sent the following example to all research teachers:

A rectangular triangle has the sides x , $x+3$, $x+6$. Compute x !

Solve the equation you get in three ways at least. Document your ways of solution in such a way, that anybody can comprehend the most important steps, you did.

Different ways	SOLVE	Graph	Table	per hand	FACTOR
percent	93%	50%	39%	4%	3%
number of ways	0 way	1 way	2 ways	3 ways	more than 3 ways
percent	7%	35%	18%	30%	10%

Studying the table you can see that nearly all students (93%) used the command **SOLVE**. The students first entered the equation $(x+6)^2 = (x+3)^2 + x^2$ and then most of them took the TI-command **SOLVE** to get the result.

As hoped for, 58% of the students found at least a second way (table or graph).

It was surprising though, which variants of right ways were found by the students. The following two variants of solution strongly influenced the further mathematical education.

Some students saved the equation $(x+6)^2 = (x+3)^2 + x^2$ without changing it as function $y1(x)$. In this case the table showed *true* for $x=9$.

F1	F2	F3	F4	F5	F6
Setup	Cell	Home	Del	Pol	Int
x	y1				
5.	false				
6.	false				
7.	false				
8.	false				
9.	true				
10.	false				
11.	false				
12.	false				
x=9.					
MAIN RAD AUTO FUNC					

This way infrequently leads to the right solution with equations, but it is a very good way for inequalities!

F1	F2	F3	F4	F5	F6
Setup	Cell	Home	Del	Pol	Int
x	y1	y2			
-3.	true	false			
-2.	false	false			
-1.	false	true			
0.	false	true			
1.	false	true			
2.	false	true			
3.	false	true			
4.	false	false			
x=-3.					
MAIN RAD AUTO FUNC					

F1	F2	F3	F4	F5	F6
Algebra	Calc	Other	Prgm	IO	Clean Up
$(x+6)^2 = (x+3)^2 + x^2 \rightarrow y1(x)$ Done $x^2 - 2 \cdot x - 3 < 0 \rightarrow y2(x)$ Done $\text{solve}((x+6)^2 = (x+3)^2 + x^2, x)$ $x = 9 \text{ or } x = -3$ $\text{solve}(x^2 - 2 \cdot x - 3 = 0, x)$ $x = 3 \text{ or } x = -1$					
MAIN RAD AUTO FUNC 4/30					

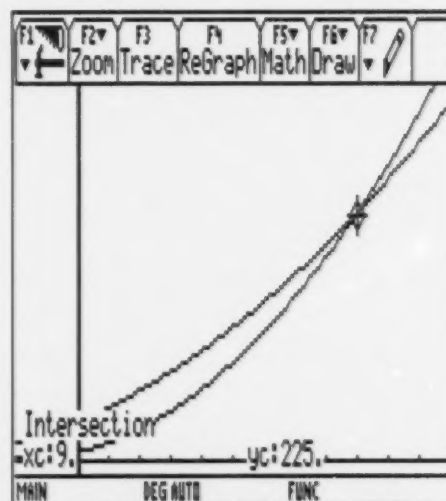
Some students saved the expression $(x+6)^2$ under $y1(x)$ and the expression $(x+3)^2+x^2$ under $y2(x)$ and they found that the *value of y is the same* (=225) in both tables when $x=9$. The students found this way in analogy to the way of solution for a system of linear equations with two variables!

F1	F2	F3	F4	F5	F6
Algebra	Calc	Other	PrgmIO	Clean Up	
$(x+6)^2 \rightarrow y1(x)$ Done $(x+3)^2 + x^2 \rightarrow y2(x)$ Done $\text{solve}((x+6)^2 = (x+3)^2 + x^2, x)$ $x = 9 \text{ or } x = -3$					
MAIN DEG AUTO FUNC 3/30					

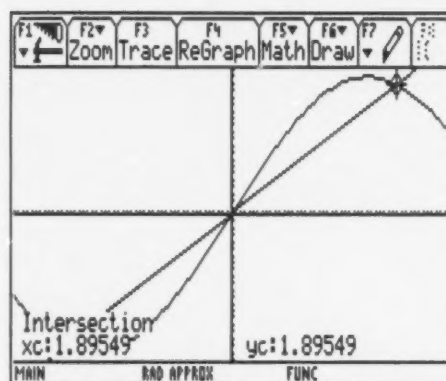
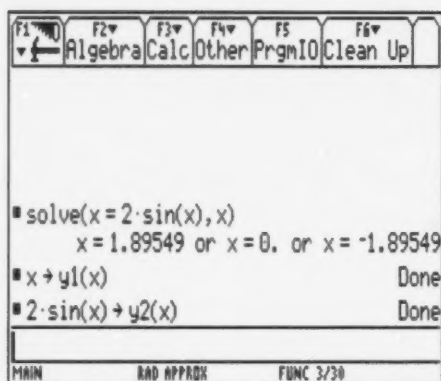
F1	F2	F3	F4	F5	F6
Setup	Table	Draw	Del	Pol	Int
x	y1	y2			
4.	100.	65.			
5.	121.	89.			
6.	144.	117.			
7.	169.	149.			
8.	196.	185.			
9.	225.	225.			
10.	256.	269.			
11.	289.	317.			
x=9.					
MAIN		RAD AUTO		FUNC	

The way with two tables produces the basis for the right understanding of the graphic way for the intersection of two curves (TI-command INTERSECTION).

F1	F2	F3	F4	F5	F6
Algebra	Calc	Other	PrgmIO	Clean Up	
$(x+6)^2 \rightarrow y1(x)$ Done $(x+3)^2 + x^2 \rightarrow y2(x)$ Done $\text{solve}((x+6)^2 = (x+3)^2 + x^2, x)$ $x = 9 \text{ or } x = -3$					
MAIN DEG AUTO FUNC 3/30					



This graphic way for the intersection of two curves (TI-command INTERSECTION) is very important for the solution of algebraic equation such as $x = 2 \cdot \sin(x)$ in the 10th form!



After having done a sequence of lessons of **quadratic equations and quadratic functions**, the teachers had to give the following example as final test:

Solve the quadratic equation $x^2 + 3x - 15 = 0$ in four different methods (one without the TI-92 and three with the TI-92)!

Every teacher had to state with which different methods the students had solved the problem given and then had to write a short report. In my class I did not only want to find out **which ways of solution the students would choose**, I also wanted to know which of the ways they chose **in first** and which **in second position**.

Distribution of the methods of my 25 students:

22x **SOLVE** (18x in 1st position),
 21x **the formula for solution** (5x in 1st, 14x in 2nd position, 4x with mistakes in calculation),
 9x **graphical method**, 8x **INTERSECTION**, 3x **Table** (counted only with stepwise 0.1),
 6x **Vieta** (can be regarded only as a check over in this case)
 2x **quadratic complement**, 2x **FACTOR**

Distribution according to the number of ways of solution:

number of ways	0 way	1 way	2 ways	3 ways	≥ 4 ways
number of students	0	5	5	3	12

Distribution according to the ways carried out successfully:

number of ways	0 way	1 way	2 ways	3 ways	≥ 4 ways
number of students	1	5	6	2	11

Considering the instruction the students had been given I was surprised to see that the **method table** (stepwise 1 was not counted) and the method using the command **FACTOR** were so little used.

After all the reports had been collected and studied, it could be proved that **the use of the TI-92 really led to a greater variation of ways of solution** when approaching a problem for in some classes students had found up to **nine different ways of solution**.

The second sequence concerning **analytic geometry** was taught at the end of the year.

The teachers had to observe how the students liked to solve **analytic problems with modules offered by the TI-92** such as norm, unitv, dotp and crossp or if they also tried to find functions of their own. The results of the observations were very different and presumably depended on whether teachers were ready to apply the modular method in a useful way in their lessons.

The **first pretest** was carried out in **21 classes** whereas the **second pretest** was carried out in **14 classes only**. **Two reasons** probably account for that:

- The **second pretest** was carried out **after having finished teaching analytic geometry**. That means it was carried out at the end of term and so many teachers were too busy with assessing the work of their students.
- **Solving problems with modular methods** was **new** for those research teachers not engaged in the **DERIVE** project in 1993/94 and for those who had never used little computer programs in mathematical education so far.

Test II

Compute the following examples on your TI-92 and enter your minutes on the lines indicated (IL is the TI-92 input line, OL the TI-92 output line):

Save the points A, B, P as follows: $[0;-1] \rightarrow a : [4;2] \rightarrow b : [-5;4] \rightarrow p$

(1) Compute the vector AB:

IL: $b - a$ OL: $[4;3]$

(2) Calculate the length of the vector AB using the TI-function NORM:

IL: $\text{norm}(b-a)$ OL: 5

(3) Set up the parametric equation of the line AB and save it under g:

IL: $[x;y]=a+t.(b-a) \rightarrow g$ OL: $[x=4t; y=3t-1]$

(4) Save a vector which is orthogonal to the vector AB under n:

IL: $[-3;4] \rightarrow n$ OL: $[-3;4]$

(5) Eliminate the parameter in equation (3) using the inner product of g and n:

IL: $\text{dotp}(g,n)$ OL: $-3x+4y=-4$

(6) Compute the midpoint of the line segment AB and save it under m:

IL: $(a+b)/2 \rightarrow m$ OL: $[2;1/2]$

(7) Set up the parametric equation of the perpendicular bisector of AB:

IL: $[x;y]=m+t.n$ OL: $[x=-3t+2; y=4t+1/2]$

(8) Compute the unit vector of AB with the formula taught and then compare it with the result of the TI-function UNITV:

IL: $(b-a)/\text{norm}(b-a)$ OL: $[4/5;3/5]$

IL: $\text{unitv}(b-a)$ OL: $[4/5;3/5]$

(9) Calculate the perpendicular distance of the point P from the line AB with the formula taught:

IL: $\text{dotp}(p-a, \text{unitv}(n))$ OL: 7

(10) Compute the direction vector of the angle bisector of (AB,AP) to 3 digits:

IL: $\text{unitv}(b-a)+\text{unitv}(p-a)$ OL: $[0.093;-1.307]$

The following table shows the achievement of the 14 classes having participated in pretest I and II:

Statistics of the student achievements				
14 classes	right $\geq 80\%$	right $> 50\%$	right $\leq 50\%$	sum
Pretest I	61%	27%	12%	100%
Pretest II	53%	36%	11%	100%

The comparison of the student achievements shows clearly that the **number of the weak students was constant**, whilst the number of the better students slightly sank with the increasing difficulty of the problems.

After the correction of pretest II the 14 research teachers asked their students to solve the following example. The set up of the working sheet was **to motivate the teachers and students to work with modules**.

Use the TI-92 when solving the following example in a skilful way and document the most important steps of your TI-92 input and output.

Triangle ABC: $A=[-3;-5]$ $B=[9;4]$ $C=[-3;9]$

a) Compute the intersection point of two perpendicular bisectors.

b) Compute the intersection point of two angle bisectors.

c) Test if the point $P=[3;-13]$ is lying on the line IU.

($I=[1;3]$ and $U=[9/8;2]$)

First sketch a diagram and then carry out the example with the help of the formulas you have been taught.

At the beginning of part a) and c) on the working sheet the following suggestion as to how the input could be stored was given:

a) Input: $[-3;-5] \rightarrow a$: $[9;4] \rightarrow b$: $[-3;9] \rightarrow c$
 b) Input: $[3;-13] \rightarrow p$: $[1;3] \rightarrow i$: $[9/8;2] \rightarrow u$

Statistics				
14 classes	(nearly) right	$\geq \frac{1}{2}$ right	few/wrong	sum
part a	59%	21%	20%	100%
part b	53%	15%	32%	100%
part c	59%	7%	34%	100%
a) b) and c)	43%	32%	26%	100%

All 14 research teachers, who had assessed the pretest II, sent their results. Many students at least tried to sketch out the beginning of a diagram but only few students per class tried to make a plan with formulas before beginning to compute as suggested.

The following reasons explain that the results in b) were not quite so good as in a) and c):

The computing of the intersection point of two angle bisectors is a difficult task and takes much time. Therefore some students left it out at first and did not finish it later on or when taken as second problem it took the students so much time that there was no time left to finish part c).

In the report of the **DERIVE-Project** H. HEUGL writes in 1996:

„It would be ideal if every student had a portable CAS-calculator, which could be linked up with the CAS in a computer lab, in his school bag.“

When the TI-92 was presented in Austria many research teachers of the Austrian CAS I project thought that the TI-92 was such a portable CAS-calculator. In the **Austrian CAS II Project (TI92-Project) 1997/98** the students of all the seventy research teachers wrote their tests in mathematics with the TI-92.

At their final meeting in August 1998 they collected their most important and sometimes unexpected results: (LECHNER/WURNIG, 1999)

- for solving problems it is very important **not always to insist on the use of the TI-92.**
- **difficult decision:** What **minimum knowledge of TI-commands** is an absolute must?
- **difficult decision:** What is to be the **minimum knowledge** in mathematics **without TI-92?**

Solve 2 formulas per hand according to the indicated variables!

a) $v = ?$ (no double fraction in the result!)

$$y = v \cdot t - \frac{g \cdot t^2}{2}$$

b) $h = ?$ (no double fraction in the result!)

$$e = m \cdot g \cdot h + \frac{m \cdot v^2}{2}$$

- students find **new ways with the TI-92** → more work for the teacher

- **modules and programs** are a good chance for good students

→ a new problem for bad students.

Calculate the perpendicular distance of the point P from the line AB with the formula taught:

$[0;-1] \rightarrow a$: $[-3;4] \rightarrow n$: $[-5;4] \rightarrow p$

IL: $\text{dotp}(p-a, \text{unitv}(n))$ OL: $\frac{7}{2}$

- the problems have to be **more goal oriented** → **text longer** instead of shorter.

1) The curve, which a flying object makes in the air is defined through the graph of the following function: $f(t) = 45 + 20t - 5t^2$. h means the height and t the time. **Draw the curve** of the flying object in the (t, h) - co-ordinates system by using of the TI-92 in your test book!

- a) **At what time** does the object reach the highest point of the trajectory and when does it hit the ground ($h=0$)?
 b) **In which height** does the trajectory start and when does the object reach the same height again?
Explain your answers!

- TI-92 has no floppy → **much documentation** in test book, therefore **fewer examples**.

The point $P = [-8; -3]$ is to be reflected on the line $g: 3x + 2y + 4 = 0$ (Sketch a diagram on the working sheet!) What are the co-ordinates of the reflected point?

- (a) *First solve the problem geometrically in your test book!*
 (b) *Solve the problem in an algebraic way with the methods of the analytic geometry on the working sheet!*

Write down your plan in the left column and document the important interim results in the right column! Do the calculations without the TI-92 on the flip side!

Left: steps of the plan!	right: TI-92 documentation!
P $g1: 3x + 2y + 4 = 0$ $g2 = g(\perp P, \perp g1)$ $g1 \cap g2 = \{S\}$ $S = (P + P^*)/2 \rightarrow P^* = 2S - P$	$[-8; -3] \rightarrow p$ $[3; 2] \rightarrow n$ $X = P + t \cdot n$ $[x = 3t - 8, y = 2t - 3]$ $3 \cdot (3t - 8) + 2 \cdot (2t - 3) + 4 = 0$ $SOLVE(ans(1), t) \quad t = 2$ $S = [-2; 1]$ $P^* = [4; 5]$

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